X-Rays Open New Frontiers in Engine Research

ARGONNE NATIONAL LABORATORY

The Challenge

Advances in optical-laser research techniques have given scientists and engineers unprecedented views of the inner workings of gasoline and diesel engines. Yet, even today, researchers cannot directly observe all the details of an engine at work — a major barrier to further improvements in engine design, efficiency, and emissions reduction.

The Solution

Argonne researchers believe that the use of x-rays will usher in a new era in engine research. Ongoing multidisciplinary research at Argonne's Advanced Photon Source (APS) will help bridge the gap between applied and basic research. Argonne has already demonstrated the usefulness of x-rays for engine research at ambient temperatures and pressures with its recent groundbreaking experiments using synchrotron radiation from the APS. Construction of a special experimental chamber at Argonne will be the first step in developing an x-ray-transparent engine that allows testing in a temperature-pressure environment that approximates the real-world conditions of an engine.

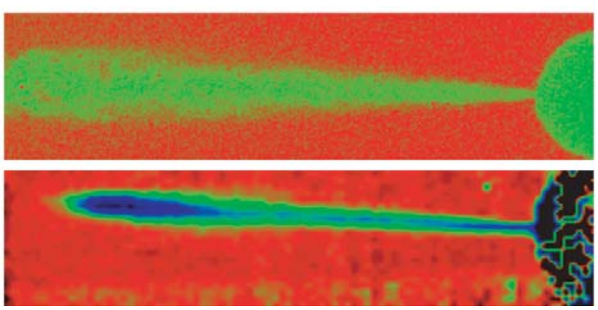

Figure 1. Unlike conventional optical techniques (top), x-rays provide quantitative data on the interior of fuel sprays.

The Foundation

Using synchrotron x-rays from the APS, scientists and engineers have achieved breakthrough results on engine-fluid dynamics, fuel-spray behavior, and combustion processes, as described below.

Fuel Spray

In 1999, researchers obtained the first-ever detailed, quantitative fuel-spray data in optically dense regimes that cannot be studied with optical-laser devices. This breakthrough in diesel-engine research earned Argonne a *Discover Magazine* Finalist Award. Later, Argonne scored another first when researchers detected evidence of shock-wave formation during the injection cycle, which can affect the combustion process. Additional research has shown that x-ray techniques can measure the properties of spray particles that affect combustion behavior. Neither optical-laser techniques nor non-optical approaches (droplet collection, use of probes) can "measure" such properties deep inside the spray (Figure 1).

Quantitative fuel-spray data will enable engineers to design fuel-injection system components that achieve higher efficiency and lower emissions.

Soot Formation

X-ray applications have given researchers new insights into soot-particle formation during combustion. By scattering x-rays off soot particles as they form in different flames, chemists have successfully determined particle distribution at sizes on the order of a nanometer — 10 times smaller than characterizations possible using optical-laser techniques. The nanometer-scale particles represent the earliest stage of soot formation ever seen, providing valuable data needed to validate soot-formation models. Next, researchers plan to simulate the combustion process with enough complexity to model the formation and reaction of soot particles.

By comparing simulations of the combustion process with observations, researchers gain a better understanding of the chemistry of soot formation and reaction. Knowing the mechanisms that govern the early stages of soot formation will lead to more effective emissions controls.

Computer Modeling

Argonne researchers, working on computer models of spray injection phenomena, have identified two promising approaches:

- Front-Tracking Methodology, an adaptive computational method for the solution of fluid-flow problems that require the tracking of sharp discontinuities (fronts) in the flow field, such as shock waves and liquid-gas interfaces (i.e., jet interfaces, droplets).

- Lattice-Boltzman Methodology, a mathematical model that describes fluid motion at the mesoscopic level. More general than currently used equations, it allows researchers to simulate a wider range of hydrodynamic phenomena.

No current codes can successfully simulate spray breakup and its evolution in the near-injector region; these data are essential in defining the initial conditions of the combustion cycle.

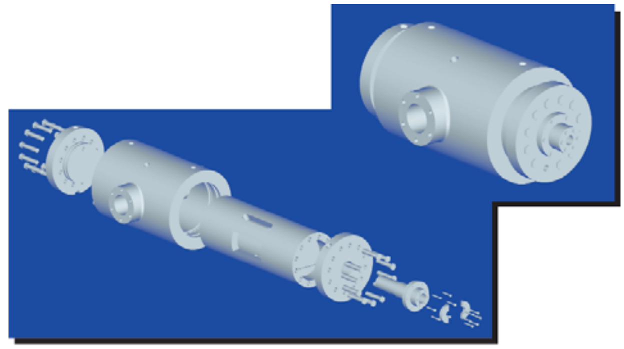

Figure 2. Isometric drawing of pressurized spray chamber with x-ray-accessible windows.

What's Next?

Argonne has designed and constructed a pressurized spray chamber for future x-ray engine research (Figure 2). The special sliding design of the chamber allows scanning of the spray plume with the beam through small x-ray-transparent windows. High-pressure sprays (diesel, gasoline engines) can be tested in this chamber under conditions similar to those encountered in working engine cylinders.

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